

LHC diboson excesses as an evidence for a heavy WW resonance

B.A. Arbuzov, I.V. Zaitsev

Lomonosov Moscow State University, Leninskie gory 1, 119991 Moscow, RF

Abstract

Recently reported diboson excesses at LHC are interpreted to be connected with heavy WW resonance with weak isotopic spin 2. The resonance appears due to the wouldbe anomalous triple interaction of the weak bosons, which is defined by well-known coupling constant λ . We obtain estimates for the effect, which qualitatively agree with ATLAS data. Effects are predicted in inclusive production of W^+W^+ , $W^+(Z, \gamma)$, W^+W^- , $(Z, \gamma)(Z, \gamma)$, $W^-(Z, \gamma)$, W^-W^- resonances with $M_R \simeq 2 TeV$, which could be reliably checked at the upgraded LHC with $\sqrt{s} = 13 TeV$. In the framework of an approach to the spontaneous generation of the triple anomalous interaction its coupling constant is estimated to be $\lambda = -0.017 \pm 0.005$ in an agreement with existing restrictions.

Keywords: anomalous triple boson interaction, W-ball, spontaneous generation of an effective interaction

PACS: 12.15.Ji, 12.60.Cn, 14.70.Fm, 14.70.Hp

1. Heavy WW resonance

In experiment [1] indications for excesses in the production of boson pairs WW, WZ, ZZ were observed at invariant mass $M_R \simeq 2 TeV$. Data for these processes are also present in works [2, 3]. Despite the fact that the wouldbe effect is not finally established yet, the publication causes numerous proposals for an interpretation mostly in terms of theories beyond the Standard Model [4, 5, 6, 7, 8, 9], for the further exhaustive list of references see [10].

However it would be advisable to consider for the beginning a possibility for a more conventional interpretation. Indeed, pair of triplets W^a could form a resonance state, the so-called W-ball. Of course the well known gauge interaction of these bosons with coupling $g(M_W) = 0.65$ can not bind them in the resonance state with mass being of a TeV scale. However, there might exist also an additional effective interaction, *e.g.* the anomalous triple boson interaction [11, 12], which increases with increasing energy scale. In case the interaction becomes sufficiently strong at a TeV scale, it might lead to a formation of a resonance under discussion. We shall consider this possibility in more details below. But firstly we would discuss if this option could be reconciled with present data [1, 2, 3].

Let us assume an existence of a resonance in a system of two W-s. There are few options in the framework of the assumption. Boson W has the unity weak isotopic spin.¹ Thus a resonance can have one of possible three values of the isotopic spin: 0, 1, 2. There is also a correlation of values of a spin and an isotopic spin. There are the following options for low spin resonances.

1. Resonance X_1 with spin 1 and isotopic spin 1. Then it can not have decay channel to ZZ and so it does not correspond to data [1].

2. Resonances X_0, X_2 with spin 0, where a subscript indicate a value of an isotopic spin. The first option X_0 is excluded due to the presence in data [1] of the decay channel $X \rightarrow WZ$.

Thus we are left with option $X_2 \equiv X_{ab}$ of a scalar resonance with the isotopic spin two. Under this premise we have the following effective interaction

$$L_{eff} = \frac{G_X}{4} X_{ab} W_{\mu\nu}^c W_{\mu\nu}^d \times \left(\frac{1}{2} (\delta_c^a \delta_d^b + \delta_d^a \delta_c^b) - \frac{1}{3} \delta^{ab} \delta_{cd} \right); \quad (1)$$

and five charge states of X_{ab}

$$X^{++}, X^+, X^0, X^-, X^{--}. \quad (2)$$

Email address: arbuzov@theory.sinp.msu.ru (B.A. Arbuzov)

¹ In what follows we omit *weak* in respect to an isotopic spin for the sake of a brevity.

Interaction (1) corresponds to the following form of the effective vertices for different charge states with momenta and indices of W -s $(p, \mu), (q, \nu)$

$$\begin{aligned}
X^{++}W^-W^- &: -i G_X (g_{\mu\nu}(pq) - p_\nu q_\mu); \\
X^+W^-W^0 &: -i \frac{G_X}{\sqrt{2}} (g_{\mu\nu}(pq) - p_\nu q_\mu); \\
X^0W^+W^- &: -i \frac{G_X}{\sqrt{6}} (g_{\mu\nu}(pq) - p_\nu q_\mu); \quad (3) \\
X^0W^0W^0 &: -i G_X \sqrt{\frac{2}{3}} (g_{\mu\nu}(pq) - p_\nu q_\mu); \\
X^-W^+W^0 &: -i \frac{G_X}{\sqrt{2}} (g_{\mu\nu}(pq) - p_\nu q_\mu); \\
X^{--}W^+W^+ &: -i G_X (g_{\mu\nu}(pq) - p_\nu q_\mu).
\end{aligned}$$

For the neutral boson we have as usually the Weinberg mixture of the Z -boson and the photon

$$W^0 = Z \cos \theta_W + A \sin \theta_W; \quad (4)$$

Effective coupling constant G_X is related to width Γ_X of the resonance

$$G_X^2 = \frac{\sqrt{M_X^2 - 4M_W^2} (M_X^2 - 4M_W^2 + 6M_W^4/M_X^2)}{64\pi}. \quad (5)$$

Data [1] allow to estimate Γ_X to be few hundreds GeV by an order of magnitude. Thus we shall present estimates of cross sections for three values of the width

$$\begin{aligned}
\Gamma_X = 200 \text{ GeV}; \quad G_X &= \frac{0.002253}{\text{GeV}}; \\
\Gamma_X = 300 \text{ GeV}; \quad G_X &= \frac{0.002759}{\text{GeV}}; \quad (6) \\
\Gamma_X = 400 \text{ GeV}; \quad G_X &= \frac{0.003186}{\text{GeV}}.
\end{aligned}$$

With values for effective couplings (6) and the mass of the resonance $M_X = 2000 \text{ GeV}$ we calculate cross sections of the resonances production at two energies: $\sqrt{s} = 8 \text{ TeV}$ for the sake of comparison with data [1] and $\sqrt{s} = 13 \text{ TeV}$ in view of a prediction of possible effects at the upgraded LHC. Calculations are performed with application of CompHEP package [13] and a necessary information from PDG [14]. The results are presented in Tables.

In the last six lines of the Tables we show results with no difference in sign of W^\pm charge and specification of the neutral component to be either Z or the photon, that could be confronted with data [1]. We see, that cross sections being around few fb for channels WW , WZ , ZZ at $\sqrt{s} = 8 \text{ TeV}$ qualitatively correspond to data collected with integral luminosity 20 fb^{-1} . For more definite conclusions one has to wait for hopefully forthcoming new data. In any case the most promising process here is a production of same positive sign W pairs.

Table 1.

Cross sections of X states production for $\sqrt{s} = 8 \text{ TeV}$ at the LHC and different channels for three values of the total width.

\sqrt{s}	8 TeV		
$\Gamma_X \text{ GeV}$	200	300	400
$\sigma(X^{++}) \text{ fb}$	2.25	3.36	4.49
$\sigma(X^+) \text{ fb}$	1.98	2.89	4.04
$\sigma(X^0) \text{ fb}$	1.33	2.05	2.65
$\sigma(X^-) \text{ fb}$	0.61	0.95	1.24
$\sigma(X^{--}) \text{ fb}$	0.22	0.33	0.45
$\sigma(WW) \text{ fb}$	2.91	4.37	5.82
$\sigma(WZ) \text{ fb}$	2.00	2.95	4.05
$\sigma(W\gamma) \text{ fb}$	0.60	0.89	1.22
$\sigma(ZZ) \text{ fb}$	0.53	0.81	1.05
$\sigma(Z\gamma) \text{ fb}$	0.31	0.49	0.63
$\sigma(\gamma\gamma) \text{ fb}$	0.047	0.073	0.094

Table 2.

Cross sections of X states production for $\sqrt{s} = 13 \text{ TeV}$ at the LHC and different channels for three values of the total width.

\sqrt{s}	13 TeV		
$\Gamma_X \text{ GeV}$	200	300	400
$\sigma(X^{++}) \text{ fb}$	17.9	26.9	35.8
$\sigma(X^+) \text{ fb}$	16.2	22.9	33.8
$\sigma(X^0) \text{ fb}$	11.4	18.1	23.6
$\sigma(X^-) \text{ fb}$	6.11	9.22	12.04
$\sigma(X^{--}) \text{ fb}$	2.60	3.90	5.22
$\sigma(WW) \text{ fb}$	24.3	36.8	48.9
$\sigma(WZ) \text{ fb}$	17.2	24.7	35.2
$\sigma(W\gamma) \text{ fb}$	5.20	7.39	10.7
$\sigma(ZZ) \text{ fb}$	4.49	7.13	9.30
$\sigma(Z\gamma) \text{ fb}$	2.70	4.29	5.59
$\sigma(\gamma\gamma) \text{ fb}$	0.41	0.64	0.84

2. A model for the WW resonance

Now let us consider a possibility of a heavy resonance in case of an existence of the anomalous three-boson interaction, which in conventional notations looks like

$$\begin{aligned}
\frac{g \lambda}{3! M_W^2} F \epsilon_{abc} W_{\mu\nu}^a W_{\nu\rho}^b W_{\rho\mu}^c; \quad (7) \\
W_{\mu\nu}^a = \partial_\mu W_\nu^a - \partial_\nu W_\mu^a + g \epsilon_{abc} W_\mu^b W_\nu^c;
\end{aligned}$$

where $g \simeq 0.65$ is the electro-weak coupling. The best limitations for parameter λ read [14]

$$\lambda_\gamma = -0.022 \pm 0.019; \quad \lambda_Z = -0.09 \pm 0.06; \quad (8)$$

where a subscript denote a neutral boson being involved in the experimental definition of λ . Sources of results for λ see [15, 16, 17, 18, 19]. Let us emphasize that $F \equiv F(p_i)$ in definition (7) denotes a form-factor, which is either postulated as in original works [11, 12] or it is just uniquely defined as in works on a spontaneous generation of effective interaction (7) [20, 21]. In any case the form-factor guarantees the effective interaction to act in a limited region of the momentum space. That is it vanishes for momenta exceeding scale Λ . We shall see that for the problem under discussion this scale has to be of order of magnitude of few TeV .

Let us present the expression for the form-factor, which was obtained in the approach [20, 21] for special kinematics $p_1 = 0, p_2 = -p_3 = p$

$$\begin{aligned}
u < u_0 : \\
F(0, p, -p) = F(u) &= \frac{1}{2} G_{15}^{31} \left(u \Big|_{0, \frac{1}{2}, 1, -\frac{1}{2}, -1}^0 \right) - \\
&\frac{85 g(\Lambda) \sqrt{2}}{128 \pi} G_{15}^{31} \left(u \Big|_{\frac{1}{2}, \frac{1}{2}, 1, -\frac{1}{2}, -1}^{\frac{1}{2}} \right) + \\
C_1 G_{04}^{10} \left(u \Big|_{\frac{1}{2}, 1, -\frac{1}{2}, -1}^{\frac{1}{2}} \right) &+ C_2 G_{15}^{10} \left(z \Big|_{1, \frac{1}{2}, -\frac{1}{2}, -1}^{\frac{1}{2}} \right); \\
u > u_0 : \quad F(u) &= 0; \quad u = \frac{G^2 x^2}{512 \pi^2}; \\
x = p^2; \quad u_0 &= 9.6175 = \frac{G^2 \Lambda^4}{512 \pi^2}; \\
C_1 &= -0.035096, C_2 = -0.051104; \\
g(\Lambda) &= 0.60366.
\end{aligned} \tag{9}$$

Here

$$G_{qp}^{mn} \left(u \Big|_{b_1, \dots, b_p}^{a_1, \dots, a_q} \right)$$

is a Meijer function [22] (see also convenient set of necessary formulas in book [23]). Interaction constant G in relations (9) is connected with conventional definitions in the following way

$$G = -\frac{g \lambda}{M_W^2}. \tag{10}$$

Calculations were done in the framework of an approximate scheme, which accuracy was estimated to be $\simeq (10 - 15)\%$ [24]. Would-be existence of effective interaction (7) leads to important non-perturbative effects in the electro-weak interaction. In particular, one might expect resonances to appear in the system of two W^a -bosons. A possibility of an appearance of such states (W-balls) was already discussed, *e.g.* in works [21, 25].

Let us consider a Bethe-Salpeter equation for a scalar bound state or a resonance consisting of two W . We have already noted, that such state can have two values of the weak isospin: $I = 0, I = 2$.

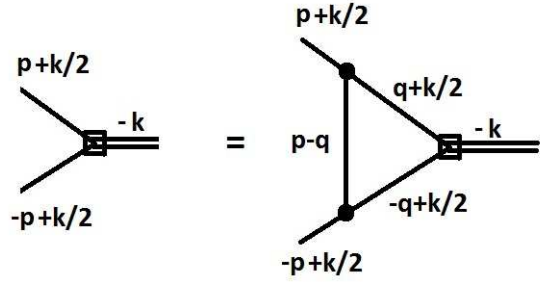


Figure 1: Diagram form of equation (11). Simple lines represent W -s, a double line corresponds to the resonance, black circles correspond to interaction (7).

With interaction (7) we have the following equation for a spin zero state in correspondence to diagrams presented in Fig 1.

$$\begin{aligned}
\Psi_R(x) &= \frac{G^2 A_I}{8 \pi^2} \left(\int_0^{\Lambda^2} D(y, v) \Psi_R(y) F^2(y) y dy + \right. \\
&\frac{1}{6x^2} \int_0^x \Psi_R(y) y^3 dy - \frac{1}{3x} \int_0^x \Psi_R(y) y^2 dy - \\
&\frac{x}{3} \int_x^{\Lambda^2} \Psi_R(y) dy + \frac{x^2}{6} \int_x^{\Lambda^2} \frac{\Psi_R(y)}{y} dy \Big); \tag{11} \\
D(y, v) &= \frac{384y^3 - 64y^2v + 20yv^2 - v^3}{64y^2(4y + v)};
\end{aligned}$$

where $A_I, I = 0, 2$ is an isotopic factor, $x = p^2$ and $y = q^2$, p and q being an external and an internal momentum in Euclidean four-momentum space, $v = k^2$ with k^2 being Euclidean four-momentum squared of the resonance state. Form-factor $F(y)$ of effective interaction (7) is introduced in the constant term of the equation. Here in view of large value $M_R \simeq 2 TeV$ of the wouldbe resonance we neglect W mass, and isotopic factor A_I is defined for different values of the total isospin I as follows

$$A_0 = -2; \quad A_2 = 1. \tag{12}$$

In equation (11) we have introduced a dependence on momentum k of the bound state only in the first constant term in the RHS part. This corresponds to approximation which is used in the approach [23]. The effective cut-off parameter Y in (11) is the same parameter, which was used in works [20, 21] in the course of studies of a spontaneous generation of interaction (7) and is defined by relations in (9)

With the following substitution for variables with account of (9)

$$\begin{aligned} z &= \frac{G^2 x^2}{64 \pi^2}; \quad t = \frac{G^2 y^2}{64 \pi^2}; \quad z_0 = \frac{G^2 \Lambda^4}{64 \pi^2} = 8 u_0; \\ \sqrt{\mu} &= \frac{G M_R^2}{8 \pi} = -\frac{G v}{8 \pi} \end{aligned} \quad (13)$$

we come to the following equation for the weak isotopic spin $I = 2$

$$\begin{aligned} \Psi_R(z) &= 4 \int_0^{z_0} D(t, \mu) \Psi_R(t) F^2(t) dt + \\ &\frac{2}{3z} \int_0^z \Psi_R(t) t dt - \frac{4}{3\sqrt{z}} \int_0^z \Psi_R(t) \sqrt{t} dt - \\ &\frac{4\sqrt{z}}{3} \int_z^{z_0} \frac{\Psi_R(t)}{\sqrt{t}} dt + \frac{2z}{3} \int_z^{z_0} \frac{\Psi_R(t)}{t} dt; \quad (14) \\ D(t, \mu) &= \frac{384t\sqrt{t} + 64t\sqrt{\mu} + 20\sqrt{t}\mu + \mu^{3/2}}{64t(4\sqrt{t} - \sqrt{\mu})}. \end{aligned}$$

Equation (14) being homogenous we choose solution under condition $\Psi_R(0) = 1$, that means

$$B = 4 \int_0^{z_0} D(t, \mu) \Psi_R(t) F^2(t) dt = 1. \quad (15)$$

By successive differentiations of equation (14) we obtain a Meijer differential equation for function $\Psi_R(z)$

$$\begin{aligned} &\left(z \frac{d}{dz} + 1\right) \left(z \frac{d}{dz} + \frac{1}{2}\right) \left(z \frac{d}{dz}\right) \left(z \frac{d}{dz} - \frac{1}{2}\right) \times \\ &\left(z \frac{d}{dz} - 1\right) \Psi_R(z) + z \Psi_R(z) = 0. \end{aligned} \quad (16)$$

Then we look for the solution in terms of Meijer functions (see *e.g.* [23]) in the following form

$$\begin{aligned} \Psi_R(z) &= \frac{1}{2} G_{15}^{31} \left(z \middle| \begin{smallmatrix} 0 \\ 0, 1/2, 1, -1/2, -1 \end{smallmatrix} \right) + \\ &C_3 G_{04}^{10} \left(z \middle| \begin{smallmatrix} 1, 1/2, -1/2, -1 \end{smallmatrix} \right) + \\ &C_4 G_{04}^{10} \left(z \middle| \begin{smallmatrix} 1/2, 1, -1/2, -1 \end{smallmatrix} \right). \end{aligned} \quad (17)$$

The substitution of (17) into equation (14) with condition (15) gives unique definition of constants:

$$C_3 = -0.0001925, \quad C_4 = 0.0015612. \quad (18)$$

Then we substitute solution (17,18) and form-factor (9) into normalization condition (15) and thus define parameter μ , which according to (13) is connected with the mass of the resonance M_R . Let us note, that in relation (15) one has to calculate the Cauchy principal value of the integral. Namely, for $\mu = 0$ in (15) we have

$B = 0.742411$. With μ increasing B also increases and $B = 1$ for

$$\mu = 0.072925. \quad (19)$$

Then from definitions (10) and (13) we have for $M_R = 2 \text{ TeV}$

$$\lambda = -0.01687. \quad (20)$$

where the sign is defined in the framework of the approach [20, 21] due to the condition of coupling constant G to be positive. This value agrees limitations (8). According to relations (9,10), value (20) corresponds to the following effective cut-off parameter

$$\Lambda = (11.4 \pm 1.7) \text{ TeV}; \quad (21)$$

where we take into account already mentioned 15% uncertainty inherent to the model. Result (21) demonstrates a natural appearance of TeV scale in the model. With account of the uncertainty in (21) our estimate (20) is to be changed for

$$\lambda = -0.017 \pm 0.005. \quad (22)$$

This result being more reliable than (20) also is quite compatible with limitations (8).

It is worth noting that for a wouldbe state with isotopic spin zero according to (12) there is an overall factor -2 in equation (11). The analogous procedure leads to the conclusion that there is no appropriate solution of the problem. We conclude, that only isotopic spin two state may be present in the framework of the present model.

3. Conclusion

Thus we consider possible five resonant states with approximate mass 2 TeV , which decay into

$$\begin{aligned} &W^+ W^+; \quad W^+ W^0; \quad W^+ W^-, W^0 W^0; \\ &W^- W^0; \quad W^- W^-. \end{aligned} \quad (23)$$

Here we have to bear in mind relation (4), which connect field W^0 with physical fields of the Z boson and of the photon. Results of calculations for cross sections of these states production are shown in Tables 1,2. The results can be reliably checked in forthcoming experiments at LHC with $\sqrt{s} = 13 \text{ TeV}$.

Assuming a spontaneous generation of the anomalous triple weak bosons interaction (7) we predict value λ (22), which also has an opportunity to be checked at the upgraded LHC.

4. Acknowledgments

The work is supported in part by the Russian Ministry of Education and Science under grant NSh-3042.2014.2.

References

- [1] G. Aad *et.al.* (ATLAS Collaboration), arXiv: 1506.00962 [hep-ex].
- [2] V. Khachatryan *et.al.* (CMS Collaboration), J High Energy Phys., 1408 (2014) p. 173, arXiv: 1405.1994 [hep-ex].
- [3] V. Khachatryan *et.al.* (CMS Collaboration), J High Energy Phys., 1408 (2014) 174, arXiv: 1405.3447 [hep-ex].
- [4] Chuang-Hung Chen and Takaaki Nomura, Phys. Lett. B 749 (2015) p. 464, arXiv: 1509.02039 [hep-ph].
- [5] L. Li, J.A. Maxin, Van E. Mayes and D.V. Nanopoulos, arXiv: 1509.06821 [hep-ph].
- [6] R.L. Avasthi, P.S. Bhupal Dev and M. Mitra, arXiv: 1509.05387 [hep-ph].
- [7] L. Bian, D. Liu, J. Su and S. Zheng, arXiv: 1508.06014 [hep-ph].
- [8] C. Petersson and R. Torre, arXiv: 1508.05632 [hep-ph].
- [9] S. Fichtel and G. von Gersdorf, arXiv: 1508.04814 [hep-ph].
- [10] D. Gonsalves, F. Krauss and M. Spannovsky, Phys. Rev. D 92 (2015) Article 053010, arXiv: 1508.04162 [hep-ph].
- [11] K. Hagiwara, R.D. Peccei, D. Zeppenfeld and K. Hikasa, Nucl. Phys. B 282 (1987) p. 253.
- [12] K. Hagiwara, S. Ishihara, R. Szalapski and D. Zeppenfeld, Phys. Rev. D 48 (1993) p. 2182.
- [13] E. E. Boos *et al.* (ComHEP Collaboration), Nucl. Instr. Meth. A 534 (2004) p. 250.
- [14] K. A. Olive *et al.* (Particle Data Group), *Review of particle physics*, Chin. Phys. C 38 (2014) p. 090001.
- [15] S. Schael *et al.* (ALEPH and DELPHI and L3 and OPAL and LEP Electroweak Collaborations) Phys. Rept. 532 (2013) p. 119, arXiv:1302.3415 [hep-ex].
- [16] G. Aad *et.al.* (ATLAS Collaboration), Phys. Rev. D 87 (2013) Article 112001.
- [17] G. Aad *et.al.* (ATLAS Collaboration), J High Energy Phys. 1501 (2015) p. 049, arXiv: 1410.7238 [hep-ex].
- [18] S. Chatrchyan *et.al.* (CMS Collaboration), Eur. Phys. J. C 73 (2013) p. 2283, arXiv: 1210.7544 [hep-ex].
- [19] S. Chatrchyan *et.al.* (CMS Collaboration), Eur. Phys. J. C 73 (2013) p. 2610, arXiv: 1306.1126 [hep-ex].
- [20] B. A. Arbuzov, Eur. Phys. J. C 61 (2009) p. 51.
- [21] B. A. Arbuzov and I. V. Zaitsev, Phys. Rev. D 85 (2012) Article 093001.
- [22] H. Bateman and A. Erdélyi, *Higher Transcendental Functions V.1*, McGraw-Hill, New-York, Toronto, London, 1953.
- [23] B. A. Arbuzov, *Non-perturbative Effective Interactions in the Standard Model*, De Gruyter, Berlin, 2014.
- [24] B. A. Arbuzov, Theor. Math. Phys. 140 (2004) p. 1205.
- [25] B. A. Arbuzov and I. V. Zaitsev, Int. J. Mod. Phys. A 27 (2012) Article 1250012.